Calcium in Dairy Products

MICHAEL H. TUNICK
Eastern Regional Research Center
Agricultural Research Service
United States Department of Agriculture
Philadelphia, PA 19118

ABSTRACT

Increasing attention has been given to the nutritional role of calcium because many Americans do not consume their Recommended Dietary Allowance of this nutrient and because calcium deficiency may lead to the development of osteoporosis or other disorders. Calcium is absorbed in the intestines with the aid of a vitamin D metabolite and is used in the body for many essential functions. There are several ways to obtain calcium in the diet, but the best sources are milk and other dairy products because of their low cost and high bioavailability of this mineral. Some manufacturers have responded to the concern over lack of calcium in the diet by increasing its levels in milk. The amount of calcium in cheese and yogurt also can be elevated.

INTRODUCTION

Dietary calcium has received much publicity recently because of its possible role in minimizing or preventing certain diseases. Most of the research on calcium in nutrition has been performed on elemental calcium and relatively little on calcium as supplied by dairy foods (67). Dairy products are rich in calcium and are responsible for about 76% of the calcium available in the American diet (27, 72). Because it is preferable to obtain a nutrient through the diet rather than by supplements (91, 123), the role of milk and milk products is important when dealing with calcium deficiency, which is the most frequent mineral deficiency in nutrition (14, 47). This review will deal with the body's need for calcium, how the body obtains it, and the role of dairy products in supplying it.

Received March 23, 1987.
Accepted July 31, 1987.

FUNCTION OF CALCIUM

Between 1.5 and 2% of the weight of the human body is calcium, over 99% of which is located in the skeleton and teeth (15, 25, 36). It is held in bone as a multiple apatite salt consisting of calcium phosphate and calcium carbonate in a crystal lattice (15). There is also a large amount of noncrystalline calcium phosphate, which may be predominant early in life (104). Bone is constantly being formed and resorbed, serving as the body's calcium reservoir. In a man weighing 70 kg, an estimated 700 mg of calcium enter and leave the bones every day (130).

Calcium not present in bone, about 10 to 12 g in an adult, plays a role in muscle contraction, normal function of nervous tissue, myocardial function, and coagulation of blood and is necessary for many enzyme functions in all biological systems (15, 25, 36). It accomplishes its effects by specific interactions with target proteins, such as the milk proteins casein and α-lactalbumin (118). The concentration of calcium in normal blood is 9 to 11 mg/dl, almost all of which is in serum. About 60% of serum calcium is in a soluble ionized form, and the rest is bound with protein and not readily diffusible (15, 25). Concentrations are precisely regulated by parathyroid hormone (PTH) and 1,25-dihydroxyvitamin D_3 [1,25-(OH_2) D_3], the metabolically active form of vitamin D. Reduced calcium causes an increase in PTH secretion, which stimulates the liver and kidneys to convert vitamin D to 1,25-$(OH)_2D_3$ (89). 1,25-Dihydroxyvitamin D_3 in the presence of PTH increases resorption of calcium from bone (26).

In recent years, calcium deficiency and low ratios of calcium to phosphorus have been implicated in a number of diseases, including osteoporosis (12, 30, 45, 46, 75, 88, 89, 94, 117), hypertension (59, 80, 102, 107), colorectal cancer (66, 92, 97, 98), and amyotropic lateral sclerosis (38). There has been a great deal of controversy surrounding these findings

(7, 41, 52, 60, 61, 78), causing the general public to become more aware of the role of calcium in diet and health.

ABSORPTION OF CALCIUM

1,25-Dihydroxyvitamin D_3 is responsible for most of the calcium absorption in the digestive tract; it induces synthesis of intestinal calcium-binding protein, which transports calcium to the plasma (95, 96, 128). The remainder of absorbed calcium is transferred by passive diffusion across intestinal mucosa (51). Absorption of calcium takes place in the duodenum and proximal jejunum within 4 h of ingestion (25). The amount of calcium in the diet does not indicate exactly the amount absorbed, since 70 to 80% is excreted in the feces (2, 131). Kidneys excrete serum calcium above 7 mg/dl (15), and an average of 15 mg/d is lost by sweating (36). The most significant influence on calcium absorption and bone mineralization is vitamin D (39). It is synthesized in the skin upon exposure to ultraviolet light and is also obtained from foods such as eggs, fatty fish, liver, and especially milk, which in the US is fortified with 10 μg vitamin D/.95 L (1qt) (36). In addition, lactose, a major ingredient of milk, increases absorption of calcium in persons who are not lactose-intolerant (10, 20). Lactose, which is not readily digestible, reaches the ileum intact (85) and apparently increases the permeability of intestinal mucosa (10). The effect of lactose on calcium absorption in persons who are deficient in the enzyme lactase (β-galactosidase) is still uncertain (20, 21, 58, 93, 101, 121). A recent study has shown that levels of calcium absorbed from milk are similar to calcium levels absorbed from yogurt in both lactase-deficient and lactase-sufficient individuals (114).

However, there are many factors that decrease absorption. Oxalic acid, found in cocoa, kale, rhubarb, soybeans, and spinach, forms calcium oxalate, which is insoluble and passes unabsorbed through the intestines (15). Phytic acid (hexaphosphoinositol), which is found in the bran portion of cereals, forms insoluble salts with free calcium in the intestines (12, 53). Calcium retention decreases with large increases in dietary caffeine (44), protein (55, 110), and sodium (44). Absorption of ingested calcium is also affected by its ratio to ingested phosphorus. A ratio between 2:1 and 1:2 appears to be best for absorbing and retaining calcium (36). However, there is evidence that no recommended ratio is necessary (34). Furthermore, it appears that orthophosphates do not decrease calcium absorption, whereas polyphosphates, which have a greater affinity for calcium, do (135). More study is needed in light of the fact that people are ingesting increasing amounts of phosphates as food additives. Other factors affecting calcium absorption include alcoholism (2), lack of physical activity (45), certain medicines (43), stress, and illness.

RECOMMENDED DIETARY ALLOWANCE

The Recommended Dietary Allowance (RDA) for calcium in the United States is established by the Food and Nutrition Board (FNB) of the National Academy of Sciences. The RDA is based on studies of calcium balance, the difference between calcium consumed in the diet and that excreted in sweat, urine, and feces. A positive balance implies that some calcium is being retained in the body. Calcium thought to be adequate for most healthy adults and children is 800 mg/d, and the RDA for pregnant women and 10 to 18-yr-olds has been established at 1200 mg/d (36).

Nutrient labeling on American food products is based on RDA derived by the FDA from the FNB data. The figure for calcium is 1000 mg/d (99). A product containing 200 mg calcium per serving will thus be labeled as having 20% of the Recommended Daily Allowance, although it has 25% of the Recommended Dietary Allowance for most people.

For over 30 yr, calcium has been one of the three nutrients most often ingested by Americans in amounts below the RDA (125). The average intake by women is particularly low — about 500 to 700 mg/d (18, 30). According to a study conducted from 1976 to 1980, two-thirds of women aged 18 to 30 and three-quarters of women over age 35 consumed less than their RDA (18, 45). One-half to three-quarters of men between ages 18 and 34 had a daily calcium intake at or above 800 mg/d, but 42% of the men above these ages consumed less than 70% of the RDA (126). A study of public school students showed that less than half received their RDA (105).

In other countries, the RDA is set lower. In the United Kingdom, for instance, 500 mg/d is considered adequate (45), and the Food and Agriculture Organization/World Health Organization suggests a daily intake of 400 to 500 mg (37). The FNB is of the opinion that such low intakes produce no advantages to the human and are therefore not recommended (36). Part of the discrepancy may be due to inaccuracies in calcium balance studies, which are quite difficult to perform (53, 61). Because of some of the findings concerning osteoporosis, a consensus panel of the National Institutes of Health has suggested raising the RDA to 1000 to 1500 mg/d (117).

Consumption of large amounts of calcium is not harmful in normal persons, since the excess is excreted and absorption can decrease at high intake levels. Ingestion of up to 2000 mg calcium/d does not result in a significant increase in urinary calcium (90). Calcium does not appear to be an important risk factor for kidney stone disease according to epidemiologic studies (90).

DIETARY SOURCES OF CALCIUM

Dairy foods are by far the leading sources of calcium in the diet (36). A quantity of .237 L (1 c) of milk or 227 g (1 c) yogurt supplies over 290 mg of calcium, and 28 g (1 oz) of many cheeses contain over 180 mg (Table 1). Consumption of .473 L (2 c) of milk along with 28 g (1 oz) of a high calcium cheese will fulfill the RDA of 800 mg calcium/d. Other foods, such as broccoli, kale, high calcium tofu, some seafood, and collard, mustard, and turnip greens, also contain significant amounts of calcium, although these foods are not eaten as frequently as dairy foods (122). Dietary supplements such as bone meal (which contains 31% calcium), calcium carbonate (40%), calcium gluconate (9%), calcium lactate (13%), and dolomite (22%) are also available (91, 122). However, bone meal contains lead, and dolomite, which is calcium carbonate and magnesium carbonate, may also contain lead (8). These two supplements are therefore not favored by physicians. Dicalcium and tricalcium phosphates, which are soluble in digestive juices, increase calcium balance in elderly patients (82). Antacids, which contain calcium carbonate as the active component, are being taken by some individuals as an inexpensive calcium source (91). Sales of calcium supplements increased by 50% in 1985 due to publicity about osteoporosis, but relying on them instead of a balanced diet could lead to improper absorption of minerals such as iron, magnesium, and zinc (123).

Therefore, the most desirable sources of calcium, both economically and nutritionally, are dairy products. The cost of obtaining the RDA of calcium by drinking milk is less than 40¢/d (73) and the cheeses listed in Table 1 can be purchased for less than 35¢/28 g (1 oz). Milk has a natural balance of nutrients and the highest biological availability of calcium of any food (57). Calcium in colloidal form is absorbed more efficiently than in ionic form (132), and about two-thirds of the calcium in milk is in colloidal suspension (50, 127) with casein, phosphorus, and citrate (54, 64). Commercially available milk has the additional advantage, not shared by other dairy products, of being fortified with vitamin D.

Milk

Calcium content of milk varies with the breed of cow. Milk from Jersey and Guernsey cows usually has over 130 mg calcium/100 g milk while Holsteins and Ayrshires generally have 120 mg/100 g or less (11). Seasonal variations in the calcium content of milk are rather small. Calcium concentrations in milk are at their lowest in July, August, and September, but the concentrations in those months are only about 10 mg/100 g lower than those in other months (54). Alteration of feed does change milk calcium (54, 64).

Ultra-high temperature processing of milk for greatly extending shelf life dates since the 1940's. Usually, the milk is heated to 130 to 150°C for 2 to 8 s and then aseptically packaged (81). Experiments with laboratory rats have shown that the absorption of calcium from UHT milk is the same as from raw or pasteurized milk (48, 129). Calcium retention in newborn infants may be higher with UHT milk (81).

In 1986, dairy processors began to market high calcium milk in response to the increased publicity over this mineral (5). When milk is fortified with tricalcium phosphate and stabilized with gum, most or all of the RDA of calcium can be obtained by drinking only one glass (.237 L; 8 oz). At present, calcium ob-

TABLE 1. Levels of calcium in dairy products (103).

Product	Serving size	Calcium, mg/serving	% RDA of calcium
Whole milk	.237 L (1 c)	291	36
Skim milk	.237 L (1 c)	302	38
Buttermilk	.237 L (1 c)	285	36
Chocolate milk	.237 L (1 c)	280	35
Yogurt, lowfat	227 g (1 c)	314–415	39–52
Ice cream or ice milk, vanilla	112 g (4 oz)	88	11
Cheeses:			
American, pasteurized process	28 g (1 oz)	174	22
Brick	28 g (1 oz)	191	24
Camembert	28 g (1 oz)	110	14
Cheddar	28 g (1 oz)	204	26
Cottage, creamed	112 g (4 oz)	68	9
Cream	28 g (1 oz)	23	3
Edam	28 g (1 oz)	207	26
Gouda	28 g (1 oz)	198	25
Limburger	28 g (1 oz)	141	18
Mozzarella, part skim	28 g (1 oz)	183	23
Neufchatel	28 g (1 oz)	21	3
Parmesan	28 g (1 oz)	336	42
Port du Salut	28 g (1 oz)	184	23
Provolone	28 g (1 oz)	214	27
Ricotta, part skim	112 g (4 oz)	337	42
Romano	28 g (1 oz)	302	38
Roquefort	28 g (1 oz)	188	24
Swiss	28 g (1 oz)	272	34

tained in this manner does not appear to have a different bioavailability than calcium obtained from regular milk. Although high calcium milk can be 50% more expensive than regular milk, consumers will not have to drink as much to reach the desired calcium intake. Also, the UHT processing extends the shelf-life of the product to 7 wk (5), another desirable feature. It has been suggested that the availability of calcium in chocolate milk is decreased because of the oxalic acid in cocoa, but studies have shown that this is not the case when normal amounts are drunk (17, 124).

Cheese

Aged cheese, which contains little or no lactose, represents a good source of calcium, particularly for lactase-deficient individuals. Calcium levels are comparatively low in soft cheeses, because these products are prepared by acid coagulation, resulting in a change in the equilibrium between the colloidal and ionic states of calcium in the milk. The calcium converts from the colloidal state, in which it is held in the curd, to the ionic state, causing at least two-thirds of it to be lost in the whey (62, 133). In addition, lower coagulation temperatures result in a conversion of colloidal calcium to the ionic form and higher temperatures apparently cause calcium and phosphate ions to form colloidal calcium phosphate (56). Various calcium concentrations in cheeses are due in part to the various temperatures of coagulation (33, 79). Calcium concentrations can be slightly raised in hard cheeses by decreasing the acidity of the curd when the whey is drained (65). It has been thought that it is not feasible to make hard cheeses fortified with extra calcium since the presence of too much of this mineral in cheese making would result in a hard inflexible curd (111). However, recent advances may enable cheese makers to manufacture products with higher amounts of calcium, which would allow consumers to reach their RDA of calcium more easily.

A relatively new method of cheese making involves the use of membrane UF. In this approach, skim milk is ultrafiltered through a semipermeable membrane, allowing only the

soluble material in the milk to pass. The retentate, which is a protein-enriched milk, is collected when its protein and moisture contents are close to those of the cheese to be prepared. Starter culture and rennet are then added as in conventional cheese making (76, 119). The UF of milk on farms and subsequent cheese manufacture have been studied in France since 1979, and American plants for the production of various cheeses from retentates are in operation or under construction (6, 63). Over 85% of milk calcium is recovered in the retentate (35), compared with the 50 to 80% recovered in conventional hard cheese manufacture (33), making UF a possible route for production of cheese with increased calcium. In several studies, calcium was measured in cheeses made by UF and traditional procedures. Mozzarella cheese samples, which had 610 mg calcium/100 g when prepared conventionally, contained 1050 mg/100 g when manufactured by UF (24). A conventional cream cheese contained 60 mg/100 g, but the UF variety had a concentration of 140 mg/100 g (22). Cottage cheese prepared by UF showed a fourfold increase in calcium compared with conventionally made cheese (23). The formation of retentates with less than 40% moisture is not currently feasible, so commercial UF of cheese milk has been confined to soft, high moisture cheeses (32).

Another membrane process that may increase calcium in cheeses is RO, in which the membrane allows only water and other small molecules to pass (40, 70). All of the calcium is held in the retentate (71). The concentrated milk, about half the original volume, can then be transported at lower cost, as with the fractionated milk produced by UF (134). Several successful attempts at manufacturing Cheddar cheese have been made on both laboratory and industrial scales (1, 13, 16, 77, 109, 134). The first calcium-enriched cottage cheese product was introduced in mid-1986. Minerals are concentrated from the whey and are added back to the curds, resulting in a calcium concentration of 300 mg/112 g (4 oz) (31).

Calcium in cheese can be increased by the addition of calcium chloride, which is permitted in the US as long as it does not exceed .02% of the weight of the milk (100). During the cheese making process, rennet-treated milk will not clot in the absence of calcium ion; as increasing amounts of calcium chloride are added to milk, coagulation time decreases to a minimum and increases again (33). In one study, cottage cheese was fortified with calcium by substitution of calcium chloride for a portion of the sodium chloride in the creaming mixture (28). According to a taste panel, 100 mg calcium/112-g (4-oz) serving was still acceptable. In another cottage cheese study (133), addition of calcium chloride to the skim milk prior to pasteurization had no effect on calcium content of the curd. Cutting the curd at pH 4.9 or 5.0 instead of pH 4.8 also produced no difference. However, by draining the whey completely and washing the curd only once, calcium increased 46%. In addition, use of 1.28-cm cheese knives instead of knives half that size caused a 60% increase in calcium content, because the larger curd exposed less surface area from which the calcium was leached. No difference in calcium content has been found between cottage cheeses made from direct acidification and conventional short set processes (74, 113).

Yogurt

Yogurt is an excellent calcium source. Because calcium forms a complex with casein, the principal milk protein, an effective way to increase the amount of calcium in yogurt is to increase protein in the product (Table 2). This may result in higher costs but would furnish the consumer with additional protein as well. Membrane techniques can also be used for yogurt, allowing for control of amount of total solids without homogenization or addition of

TABLE 2. Calcium levels in yogurt varieties (103).

Variety[1]	Milk used	Protein, g/ 227 g (1 c)	Calcium, mg/ 227 g (1 c)
Plain	Whole	7.9	274
Fruit	Lowfat	9.0	314
Fruit	Lowfat	9.9	345
Fruit	Lowfat	11.0	383
Plain	Lowfat	11.9	415
Plain	Skim	13.0	452

[1] Nonfat milk solids added to nonfat and skim milk yogurts.

milk solids (108, 120). Yogurt has been prepared from milk concentrated by RO, resulting in a decrease in whey drainage (29) and presumably an increase in calcium content. Good quality yogurts have been manufactured from UF milk as well (19, 106).

Milk Protein Products

The whey remaining from casein and cheese manufacture can serve as a calcium source for various products. Sweet whey is produced when cheese or casein are made through the action of rennet, and contains around 500 mg calcium/L (69). Acid whey results from acid coagulation of milk and contains three times as much calcium (69). Treatments such as UF and RO are often used to produce whey powders and protein concentrates, which are added to food for their functional and nutritional attributes (83). Cheeses such as ricotta are manufactured from whey and have very high amounts of calcium. Whey can also be used in many beverages, although the price might not be competitive with more popular drinks (49).

When added to food, calcium caseinate is used for such properties as emulsifying, whipping, foaming, viscosity, and texturization, and provides the added benefit of additional dietary calcium (84). It is produced by acid precipitation of casein curd from skim milk and neutralization of the curd with calcium hydroxide (83). Calcium content is typically 1.0 to 1.5% (86). Blends of whey protein and calcium caseinate are being developed for their nutritional benefits (3, 83).

When skim milk is heated until the whey proteins denature and complex with the caseins, a high calcium coprecipitate of the proteins can be formed by adding calcium chloride (86, 87). The amount of calcium can be controlled by varying amounts calcium chloride and length of heating (115). Calcium content can be up to 3%. Coprecipitates are used for many of the same properties as calcium caseinate and contribute nutritional value without affecting the flavor of the product (84, 116).

Other Products

Ice cream, one of the most popular desserts in the US and other countries, contains a significant amount of calcium. The oxide and hydroxide salts of calcium are often added to ice cream to give a creamy or rich appearance (9). Calcium sulfate is also added to improve the dryness and stiffness of the product during manufacture (9). The UF retentates can theoretically be used to produce high calcium ice cream as well as high calcium buttermilk (68). New high calcium milk drinks with varying concentrations of sodium, lactose, fat, cholesterol, and calories are also possible with membrane technology (68).

Imitation cheeses, which are cheaper and easier to handle than real cheeses, are gaining in popularity, especially in the frozen pizza industry (42). Casein and caseinate combinations are often used to impart textural properties similar to those of cheese (84). Vegetable oil and water are other ingredients (4, 112). Some imitation cheeses contain pasteurized process cheese, while others are made with no dairy products at all (4, 112).

CONCLUSIONS

Calcium, an essential nutrient, is often consumed below the recommended amounts, which could lead to various health problems. Dairy products provide the best dietary source of this mineral since normal servings of milk, cheese, and yogurt contain substantial percentages of the RDA of calcium. Alterations in the manufacture of dairy products, such as use of membrane procedures or addition of calcium salts, can raise their calcium levels even further. Additional research on dairy food calcium and its role in health is needed.

REFERENCES

1 Agbevavi, T., D. Rouleau, and R. Mayer. 1983. Production and quality of Cheddar cheese manufactured from whole milk concentrated by reverse osmosis. J. Food Sci. 48:642.

2 Allen, L. H. 1982. Calcium bioavailability and absorption: a review. Am. J. Clin. Nutr. 35:783.

3 Andres, C. 1983. Whey protein line expanded by addition of functional blends. Food Proc. 44:68.

4 Anonymous. 1982. Imitation cheese. Food Proc. 43:22.

5 Anonymous. 1986. Calcium milk products satisfy health conscious America. Dairy Field 169:21.

6 Anonymous. 1986. UF in the dairy industry. Dairy Field 169:22.

7 Anonymous. 1986. Dingell asks FDA to comment on calcium health claims. Food Chem. News 27:42.

8 Anonymous. 1986. Maximum limits on lead in bone meal requested by researcher. Food Chem. News 28:17.

9 Arbuckle, W. S. 1986. Pages 36–37 *in* Ice cream. 4th ed. AVI Publ. Co., Westport, CT.
10 Armbrecht, H. J., and R. H. Wasserman. 1976. Enhancement of Ca^{++} uptake by lactose in the rat small intestine. J. Nutr. 106:1265.
11 Armstrong, T. V. 1959. Variations in the gross composition of milk as related to the breed of cow: a review and critical evaluation of the literature of the United States and Canada. J. Dairy Sci. 42:1.
12 Avioli, L. V. 1984. Calcium and osteoporosis. Annu. Rev. Nutr. 4:471.
13 Barbano, D. M., and D. G. Bynum. 1984. Whole milk reverse osmosis retentates for Cheddar cheese manufacture: cheese composition and yield. J. Dairy Sci. 67:2839.
14 Brink, M. F. 1970. Nutritional characteristics of milk components. Page 383 *in* By-products from milk. B. H. Webb and E. O. Whittier, ed. 2nd ed. AVI Publ. Co., Westport, CT.
15 Burton, B. T. 1976. Pages 128–131 *in* Human nutrition. 3rd ed. McGraw-Hill Book Co., New York, NY.
16 Bynum, D. G., and D. M. Barbano. 1985. Whole milk reverse osmosis retentates for Cheddar cheese manufacture: chemical changes during aging. J. Dairy Sci. 68:1.
17 Campbell, J. R., and R. T. Marshall. 1975. Page 434 *in* The science of providing milk for man. McGraw-Hill Book Co., New York, NY.
18 Carroll, M. D., S. Abraham, and C. M. Dresser. 1983. Dietary intake source data: United States, 1976–80. Natl. Ctr. Health Stat., Dep. Health Hum. Serv., Washington, DC.
19 Chapman, H. R., V. E. Bines, F. A. Glover, and P. J. Skudder. 1974. Use of milk concentrated by ultrafiltration for making hard cheese, soft cheese and yoghurt. J. Soc. Dairy Technol. 27:151.
20 Cochet, B. A., M. Jung, P. Griessen, P. Bartholdi, P. Schaller, and A. Donath. 1983. Effects of lactose on intestinal calcium absorption in normal and lactase-deficient subjects. Gastroenterology 84:935.
21 Condon, J. R., J. R. Nassim, J. C. Millard, A. Hilbe, and E. M. Stainthorpe. 1970. Calcium and phosphorus metabolism in relation to lactose tolerance. Lancet 1:1027.
22 Covacevich, H. R., and F. V. Kosikowski. 1977. Cream cheese by ultrafiltration. J. Food Sci. 42:1362.
23 Covacevich, H. R., and F. V. Kosikowski. 1978. Cottage cheese by ultrafiltration. J. Dairy Sci. 61:529.
24 Covacevich, H. R., and F. V. Kosikowski. 1978. Mozzarella and Cheddar cheese manufacture by ultrafiltration principles. J. Dairy Sci. 61:701.
25 Czarnecki, S. K., and D. Kritchevsky. 1980. Trace elements. Pages 319–321 *in* Nutrition and the adult. R. B. Alfin-Slater and D. Kritchevsky, ed. Plenum Press, New York, NY.
26 DeLuca, H. F., and H. K. Schnoes. 1976. Metabolism and mechanism of action of vitamin D. Annu. Rev. Biochem. 45:631.
27 Demott, B. J. 1985. Nutrient ratios in dairy products. Cult. Dairy Prod. J. 20:6.
28 Demott, B. J. 1986. Influence of added calcium chloride upon flavor of cottage cheese. Cult. Dairy Prod. J. 21:10.
29 Dixon, B. D. 1985. Dairy products prepared from reverse osmosis concentrate–market milk products, butter, skim milk powder and yoghurt. Aust. J. Dairy Technol. 40:91.
30 Draper, H. H., and C. A. Scythes. 1981. Calcium, phosphorus, and osteoporosis. Fed. Proc. 40: 2434.
31 Duxbury, D. D. 1986. Calcium supplement derived from milk. Food Proc. 47:110.
32 Ernstrom, C. A. 1986. Use of UF/RO membranes in the dairy foods industry. Pages 55–59 *in* Status summaries. J. C. Bruhn, ed. Natl. Workshop Res. Opportunities Dairy Ind., Berkeley, CA.
33 Ernstrom, C. A., and N. P. Wong. 1974. Milk-clotting enzymes and cheese chemistry. Pages 662–771 *in* Fundamentals of dairy chemistry. B. H. Webb, A. H. Johnson, and J. A. Alford, ed. 2nd ed. AVI Publ. Co., Westport, CT.
34 Feldheim, W. 1983. Zur relation zwischen calcium and phosphor in der nahrung des menschen. Milchwissenschaft 38:284.
35 Fischbach-Greene, L., and N. N. Potter. 1986. Effect of ultrafiltration on retention of minerals and other components of milk. J. Food Sci. 51:345.
36 Food and Nutrition Board. 1980. Pages 125–133 *in* Recommended Dietary Allowances. 9th ed. Natl. Acad. Sci., Washington, DC.
37 Food and Agriculture Organization/World Health Organization (FAO/WHO). 1962. Calcium requirements. Rep. FAO/WHO expert group, FAO, United Nations, Rome.
38 Fujita, T. 1985. Aging and calcium as an environmental factor. J. Nutr. Sci. Vitaminol. 31:S15.
39 Gallagher, J. C., and B. L. Riggs. 1978. Current concepts in nutrition. Nutrition and bone disease. New England J. Med. 298:193.
40 Glover, F. A. 1971. Concentration of milk by ultrafiltration and reverse osmosis. J. Dairy Res. 38:373.
41 Gordan, G. S., and C. Vaughan. 1986. Calcium and osteoporosis. J. Nutr. 116:319.
42 Graf, T. F. 1981. The economics of imitation cheese. Pages 395–405 *in* Proc. 2nd Bienn. Marschall Int. Cheese Conf., Madison, WI.
43 Hahn, T. J., and L. R. Halstead. 1979. Anticonvulsant drug-induced osteomalacia: alterations in mineral metabolism and response to vitamin D_3 administration. Calcif. Tissue Int. 27:13.
44 Heaney, R. P. 1986. Calcium bioavailability. Contemp. Nutr. 11:1.
45 Heaney, R. P., J. C. Gallagher, C. C. Johnston, R. Neer, A. M. Parfitt, and G. D. Whedon. 1982. Calcium nutrition and bone health in the elderly. Am. J. Clin. Nutr. 36:986.
46 Heaney, R. P., P. D. Saville, and R. R. Recker. 1975. Calcium absorption as a function of calcium intake. J. Lab. Clin. Med. 85:881.
47 Heimann, W. 1980. Pages 195–196 *in* Fun-

damentals of food chemistry. Ellis Horwood Ltd., Chichester.
48 Henry, K. M., and J. Toothill. 1960. A note on the availability of the calcium of milk submitted to ultra-high-temperature sterilization with or without subsequent in-bottle sterilization. J. Dairy Res. 27:77.
49 Holsinger, V. H., L. P. Posati, and E. D. DeVilbiss. 1974. Whey beverages: a review. J. Dairy Sci. 57:849.
50 Holt, C. 1985. The milk salts: their secretion, concentrations, and physical chemistry. Pages 143–181 *in* Developments in dairy chemistry–3 P. F. Fox, ed. Elsevier Appl. Sci. Publ., London, Engl.
51 Hourigan, J. A. 1984. Nutritional implications of lactose. Aust. J. Dairy Technol. 39:114.
52 Institute for Scientific Information. 1986. Milking the calcium craze. Curr. Contents 29:10.
53 Irwin, M. I., and E. W. Kienholz. 1973. A conspectus of research on calcium requirements of man. J. Nutr. 103:1019.
54 Jenness, R., and S. Patton. 1959. Pages 158–181 *in* Principles of dairy chemistry. John Wiley & Sons, New York, NY.
55 Johnson, N. E., E. N. Alcantara, and H. Linkswiler. 1970. Effect of level of protein intake on urinary and fecal calcium and calcium retention of young adult males. J. Nutr. 100:1425.
56 Kannan, A., and R. Jenness. 1961. Relation of milk serum proteins and milk salts to the effects of heat treatment on rennet clotting. J. Dairy Sci. 44:808.
57 Kansal, V. K., and S. Chaudhary. 1982. Biological availability of calcium, phosphorus and magnesium from dairy products. Milchwissenschaft 37:261.
58 Kocian, J., I. Skala, and K. Bakos. 1973. Calcium absorption from milk and lactose free milk in healthy subjects and patients with lactose intolerance. Digestion 9:317.
59 Kok, F. J., J. P. Vandenbroucke, C. van der Heide-Wessel, and R. M. van der Heide. 1986. Dietary sodium, calcium, and potassium, and blood pressure. Am. J. Epidemiol. 123:1043.
60 Kolata, G. 1984. Does a lack of calcium cause hypertension? Science 225:705.
61 Kolata, G. 1986. How important is dietary calcium in preventing osteoporosis? Science 233: 519.
62 Kosikowski, F. V. 1977. Page 618 *in* Cheese and fermented milk products. 2nd ed. Edwards Bros., Inc., Ann Arbor, MI.
63 Kosikowski, F. V. 1985. Ultrafiltration of milk on French farms and in the making of a new speciality cheese industry. J. Dairy Sci. 68: 2403.
64 Lampert, L. M. 1970. Pages 55–57 *in* Modern dairy products. Chem. Publ. Co., New York, NY.
65 Lawrence, R. C., and J. Gillies. 1980. The assessment of the potential quality of young Cheddar cheese. N.Z. J. Dairy Sci. Technol. 15:1.
66 Lipkin, M., and H. Newmark. 1985. Effect of added dietary calcium on colonic epithelial-cell proliferation in subjects at high risk for familial colonic cancer. New England J. Med. 313:1381.
67 Lofgren, P. A., E. N. Alcantara, and E. W. Speckmann. 1986. Nutrition issues and the dairy foods industry. Pages 24–29 *in* Status summaries. J. C. Bruhn, ed. Natl. Workshop Res. Opportunities Dairy Ind., Berkeley, CA.
68 Luksas, T. 1986. New product technology. Pages 16–20 *in* Status summaries. J. C. Bruhn, ed. Natl. Workshop Res. Opportunities Dairy Ind., Berkeley, CA.
69 Marshall, K. R. 1982. Industrial isolation of milk proteins: whey proteins. Pages 339–373 *in* Developments in dairy chemistry–1. P. F. Fox, ed. Appl. Sci. Publ., London, Engl.
70 Marshall, S. C. 1985. The reverse osmosis process. Aust. J. Dairy Technol. 40:86.
71 Marshall, S. C. 1985. Reverse osmosis plant operation. Austr. J. Dairy Technol. 40:88.
72 Marston, R. M., and S. O. Welsh. 1984. Nutrient content of United States food supply, 1982. Econ. Res. Serv., US Dep. Agric., Washington, DC.
73 Martin, J. H., and M. A. Maziar. 1985. Comparative costs for recommended daily allowances of calcium and protein from various foods. Cult. Dairy Prods. J. 20:8.
74 Martin, J. H., D. E. Satterness, J. G. Parsons, and K. R. Spurgeon. 1986. Mineral content of cottage cheese made by culture method and by direct acidification. Cult. Dairy Prods. J. 21:8.
75 Matkovic, V., K. Kostial, I. Simonovic, R. Buzina, A. Brodarec, and B.E.C. Nordin. 1979. Bone status and fracture rates in two regions of Yugoslavia. Am. J. Clin. Nutr. 32:540.
76 Maubois, J. L., and G. Mocquot. 1975. Application of membrane ultrafiltration to prepration of various types of cheese. J. Dairy Sci. 58:1001.
77 Mayes, J. J. 1985. Dairy products manufactured from whole milk concentrated by reverse osmosis. Part 2–Cheddar cheese. Aust. J. Dairy Technol. 40:100.
78 Mazess, R. B., A. E. Harper, and H. DeLuca. 1985. Calcium intake and bone. Am. J. Clin. Nutr. 42:568.
79 McCammon, R. B., W. J. Caulfield, and M. M. Kramer. 1933. Calcium and phosphorus of cheese made under controlled conditions. J. Dairy Sci. 16:253.
80 McCarron, D. A. 1984. Dietary calcium as an antihypertensive agent. Nutr. Rev. 42:223.
81 Mehta, R. S. 1980. Milk processed at ultra-high-temperatures–a review. J. Food Prot. 43: 212.
82 Molimard, R., J. Postec, C. Pautas, A. Begue, J. Carbonnier, and B. Delabeye. 1985. Absorption digestive de phosphates de calcium chez l'homme. Presse Med. 14:2283.
83 Morr, C. V. 1979. Utilization of milk proteins as starting materials for other foodstuffs. J.

Dairy Res. 46:369.
84 Morr, C. V. 1982. Functional properties of milk proteins and their use as food ingredients. Pages 375–399 *in* Developments in dairy chemistry–1. P. F. Fox, ed. Appl. Sci. Publ., London, Engl.
85 Morrissey, P. A. 1985. Lactose: chemical and physicochemical properties. Page 30 *in* Developments in dairy chemistry–3. P. F. Fox, ed. Elsevier Appl. Sci. Publ., London, Engl.
86 Muller, L. L. 1971. Manufacture and uses of casein and co-precipitate. Dairy Sci. Abstr. 33:659.
87 Muller, L. L. 1982. Manufacture of casein, caseinates and co-precipitates. Pages 315–337 *in* Developments in dairy chemistry–1. P. F. Fox, ed. Appl. Sci. Publ., London, Engl.
88 National Dairy Council. 1976. Calcium in bone health. Dairy Counc. Dig. 47:31.
89 National Dairy Council. 1982. Diet and bone health. Dairy Counc. Dig. 53:25
90 National Dairy Council. 1983. Diet and urolithiasis. Dairy Counc. Dig. 54:25.
91 National Dairy Council. 1984. The role of calcium in health. Dairy Counc. Dig. 55:1.
92 National Dairy Council. 1986. Diet, nutrition, and cancer: new findings. Dairy Counc. Dig. 57:7.
93 Nielsen, O. H., P. O. Schiotz, S. N. Rasmussen, and P. A. Krasilnikoff. 1984. Calcium absorption and acceptance of low-lactose milk among children with primary lactase deficiency. J. Pediatr. Gastroent. Nutr. 3:219.
94 Nutrition Foundation. 1983. Osteoporosis and calcium balance. Nutr. Rev. 41:83.
95 Nutrition Foundation. 1984. Calcium-binding protein is induced by the active metabolite of vitamin D before intestinal calcium uptake is stimulated. Nutr. Rev. 42:27.
96 Nutrition Foundation. 1984. Altered membrane lipid composition: a possible molecular basis of vitamin D action. Nutr. Rev. 42:357.
97 Nutrition Foundation. 1985. Calcium and vitamin D intakes influence the risk of bowel cancer in men. Nutr. Rev. 43:170.
98 Nutrition Foundation. 1986. Dietary calcium and colonic epithelial cell proliferation. Nutr. Rev. 44:264.
99 Office of the Federal Register. 1985. Code of Federal Regulations. Title 21, Section 101.9. Natl. Archives and Records Admin., Washington, DC.
100 Office of the Federal Register. 1985. Code of Federal Regulations. Title 21, Section 133. Natl. Archives and Records Adm., Washington, DC.
101 Pansu, D., and M. D. Chapuy. 1970. Calcium absorption enhanced by lactase and xylose. Calcif. Tiss. Res. 4:155.
102 Parrott-Garcia, M., and D. A. McCarron. 1984. Calcium and hypertension. Nutr. Rev. 42:205.
103 Posati, L. P., and M. L. Orr. 1976. Composition of foods. Dairy and egg products. Agric. Res. Serv., US Dep. of Agric., Washington, DC.
104 Posner, A. S. 1969. Crystal chemistry of bone mineral. Physiol. Rev. 49:760.
105 Radzikowski, J. 1983. The national evaluation of school nutrition programs: final report–executive summary. US Dept. of Agric., Washington, DC.
106 Renner, E. 1986. Nutritional aspects of fermented milk products. Cult. Dairy Prods. J. 21:6.
107 Resnick, L. M. 1985. Calcium and hypertension: the emerging connection. Ann. Int. Med. 103: 944.
108 Robinson, R. K., and A. Y. Tamime. 1986. Recent developments in yoghurt manufacture. Pages 1–34 *in* Modern dairy technology. Volume 2: advances in milk products. R. K. Robinson, ed. Elsevier Appl. Sci. Publ., London.
109 Schmidt, D., I. A. Fedrick, and H. M. Donovan. 1986. Quality and yield of cheddar cheese manufactured from reconstituted reverse osmosis milk concentrates. N.Z. J. Dairy Sci. Technol. 21:125.
110 Schuette, S. A., and H. M. Linkswiler. 1982. Effects on Ca and P metabolism in humans by adding meat, meat plus milk, or purified proteins plus Ca and P to a low protein diet. J. Nutr. 112:338.
111 Scott, R. 1981. Page 105 *in* Cheesemaking practice. Appl. Sci. Publ. Ltd., London, Engl.
112 Shaw, M. B. 1986. Modern cheesemaking: soft cheeses. Pages 159–214 *in* Modern dairy technology. Vol. 2. Advances in milk products. R. K. Robinson, ed. Elsevier Appl. Sci. Publ., London, Engl.
113 Sinha, D. K., K. M. Shahani, A. Kilara, and R. M. Hill. 1979. Calcium, magnesium and phosphorus contents of cultured and acidified cottage cheese. Cult. Dairy Prod. J. 14:21.
114 Smith, T. M., J. C. Kolars, D. A. Savaiano, and M. D. Levitt. 1985. Absorption of calcium from milk and yogurt. Am. J. Clin. Nutr. 42: 1197.
115 Southward, C. R., and R. M. Aird. 1978. Coprecipitates and their application in food products I. Observations on the manufacture of co-precipitates. N.Z. J. Dairy Sci. Technol. 13:77.
116 Southward, C. R., and A. Goldman. 1978. Coprecipitates and their application in food products II. Some properties and applications. N.Z. J. Dairy Sci. Technol. 13:97.
117 Spencer, H., and L. Kramer. 1986. Factors contributing to osteoporosis. J. Nutr. 116:316.
118 Stuart, D. I., K. R. Acharya, N.P.C. Walker, S. G. Smith, M. Lewis, and D. C. Phillips. 1986. α-Lactalbumin possesses a novel calcium binding loop. Nature 324:84.
119 Sutherland, B. J., and G. W. Jameson. 1981. Composition of hard cheese manufactured by ultrafiltration. Aust. J. Dairy Technol. 36:136.
120 Tamime, A. Y., and H. C. Deeth. 1980. Yogurt: technology and biochemistry. J. Food Prot. 43:939.
121 Tremaine, W. J., A. D. Newcomer, B. L. Riggs,

and D. B. McGill. 1986. Calcium absorption from milk in lactase-deficient and lactase-sufficient adults. Dig. Dis. Sci. 31:376.
122 Tufts University. 1984. A hard act to follow: getting more calcium. Diet Nutr. Lett. 2:3.
123 Tufts University. 1986. Efforts to curb supplement abuse are stepped up. Diet Nutr. Lett. 4:1.
124 Tufts University. 1986. Ask the experts. Diet Nutr. Lett. 4:8.
125 United States Department of Agriculture. 1957. Dietary levels of households in the United States. Household food consumption survey, 1955. Rep. 6, Agric. Res. Serv., US Dep. Agric., Hyattsville, MD.
126 United States Department of Agriculture. 1980. Food and nutrient intakes of individuals in 1 day in the United States. Spring 1977. Nationwide food consumption survey 1977–1978. Preliminary Rep. 2. Consumer Nutr. Ctr., US Dep. Agric., Hyattsville, MD.
127 Verma, I. S., and H. H. Sommer. 1957. Study of the naturally occurring salts in milk. J. Dairy Sci. 40:331.
128 Wasserman, R. H., and A. N. Taylor. 1966. Vitamin D_3-induced calcium-binding protein in chick intestinal mucosa. Science 152:791.
129 Weeks, C. E., and R. L. King. 1985. Bioavailability of calcium in heat-processed milk. J. Food Sci. 50:1101.
130 Whedon, G. D. 1964. The combined use of balance and isotopic studies in the study of calcium metabolism. Pages 425–438 *in* Proc. VI Int. Congr. Nutr. C. F. Mills and R. Passmore, ed. E. & S. Livingstone, Ltd., Edinburgh, Scotland.
131 Wilkinson, R. 1976. Absorption of calcium, phosphorus and magnesium. Pages 36–112 *in* Calcium, phosphate and magnesium metabolism. B.E.C. Nordin, ed. Churchill Livingstone, New York, NY.
132 Wong, N. P., and D. E. LaCroix. 1980. Biological availability of calcium in dairy products. Nutr. Rep. Int. 21:673.
133 Wong, N. P., D. E. LaCroix, W. A. Mattingly, J. H. Vestal, and J. A. Alford. 1976. The effect of manufacturing variables on the mineral content of cottage cheese. J. Dairy Sci. 59:41.
134 Zall, R. R. 1984. Membrane processing of milk on the dairy farm. Food Technol. 38:88.
135 Zemel, M. B., and H. M. Linkswiler. 1981. Calcium metabolism in the young adult male as affected by level and form of phosphorus intake and level of calcium intake. J. Nutr. 111:315.